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Agricultural Memorandum No. 630

Ventilated onion bulk storage temperatures - a simulation study

0117318

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1. Introduction

If local grown onions can be kept satisfactorily until the late spring or early summer, then the existing acreages allocated to ware onions offer a potential import saving at the present time of at least £2M a year. If practical procedures can be developed to control onion bulk temperatures, then this possible annual import saving would undoubtedly increase.

The primary determinant of regrowth has been taken to be the onion bulk temperature with ambient relative humidity internal to the bulk an important but secondary consideration.

This note is concerned solely with the bulk temperatures that might be achieved with automatic ventilation.

2. Basic data

The following data have been employed in calculations.

Heat transfer coefficient (in a ventilated bulk) between the onions and the ventilating air = 1.31 Btu/hour/ft^2/deg F.

Surface area of onions (at 0.2 ft diameter) = 17.82 ft^2/ft^3 of bulk.

Bulk density = 80 ft^3/ton.

Specific heat of onions = 0.83 Btu/lb/deg F.

Metabolic heat output of onions
= 30 Btu/ton/hour at 0°C.
= 50 " " " " 5°C.
= 70 " " " " 10°C and above.

The units are quoted in their original formulation.

3. Bulk ventilation rates

We are concerned here not with any initial curing of the onions at high temperatures, but with the maintenance of low temperatures within the bulk by blowing with cool, outside air.

There are limitations to the temperature lift of the ventilating air. In the forced, turbulent convective heat exchange we envisage, the temperature of the air leaving the bulk cannot exceed the temperature of the bulk; it may be less than the bulk temperature under high volume flow rates, but we have examined only the case where the fan rating is such that this last alternative never arises. The temperature of the air leaving the bulk has been assumed to be close to that of the bulk.

In the calculations, the simplest assumptions were made, namely that the progress of the cooling front could be ignored, that ventilation would be sufficiently frequent to remove temperature gradients, so that the bulk could be considered to be at a uniform temperature. The temperature consequences of the concommitant moisture exchanges between the bulk and the ventilating air were assumed to be written into the value of the specific heat adopted.

If ventilation of 1 ton of onions for 1 hour causes its temperature to fall by (Δ T) deg F, the heat loss of the onions is given by the expression.

Heat loss = Mass x specific heat x temperature change
= 2240 x 0.83 x (Δ T)
= 1859 (Δ T) Btu

The heat uptake of the ventilating air is given by the expression.

Heat gain = Heat transfer coefficient x surface area x mean temperature difference between the bulk and air temperatures (T*)
= 1.31 x 80 x 17.82 x T*
= 1867 T* Btu

An alternative expression for the heat uptake of the cool ventilating air involves the volume flow rate V (cfm/ton) and air density (12.75 lb/ft^3). The specific heat of air is taken as 0.24 Btu/lb/deg F.

Heat gain = Mass x specific heat x temperature change

$$= \frac{V \times 60}{12.75} \times 0.24 \times (dT)$$

Equating numerical expressions for heat loss and heat gain, we have

$$1859\ \Delta T = \frac{V \times 60}{12.75} \times 0.24 \times dT$$

or $$\boxed{\Delta T = 0.0006\ V.dT}$$

The combination of the flow rate (V.cfm/ton) and temperature difference between the onion bulk and the ventilating air (dT), which would lower the temperature of the bulk in 1 hour, by 1 deg F, i.e. Δ T = 1 deg F are

V = 50 cfm/ton	dT = 33.9 deg F
V = 100	dT = 16.5
V = 200	dT = 8.2

Recalling that a doubling of flow rates must involve a squaring of fan power requirements, then it is seen that at the economic flow rates that can be generated by typical axial flow fans, an initial temperature difference of the order 16 deg F can be accepted, at flow rates of the 100 cfm/ton, before a significant temperature difference between the bulk and the emerging ventilating air begins to occur.

4. The temperature of the ventilating air

Given access to a programmable calculator, it was possible to consider heat balances and temperature changes of the onion bulk on an hourly basis.

It was assumed that hourly air temperatures might, with sufficient accuracy, be generated from the daily maximum and minimum air (screen) temperatures.

Over the period between the time of the air temperature minimum (taken as sunrise) and the time of the air temperature maximum (taken as noon + 2 hours in winter; noon + 3 hours in summer) the air temperature T at time (t) was obtained by fitting a cosine function of the form.

$$T(t) = \left[\frac{T_n + T_x}{2}\right] + \left[\frac{T_n - T_x}{2}\right] \cos\left(180^\circ \frac{t}{F_1}\right)$$

where $T(t)$ = temperature at time t hours measured from a zero at sunrise

T_n = minimum air temperature

T_x = maximum air temperature

F_1 = half the daylight hours + the time delay from noon to the daily temperature maximum

Over the period between the maximum air temperature on one day and the minimum air temperature (at sunrise) on the next, the temperature at time t was obtained from the relationship.

$$T(t) = \left[\frac{T_x + T_{n+1}}{2}\right] \left[\frac{T_x - T_{n+1}}{2}\right] \left(180^\circ \frac{t}{F_2}\right)$$

where T_{n+1} = minimum air temperature on the day following that on which T_x is observed

F_2 = $24 - F_1$

t is measured from a zero at sunrise on the day of T_{n+1} i.e. all times are negative

Over the period between October and May, the, following values of F_1 and F_2 were adopted.

	F_1	F_2
October	7	17
November	7	17
December	6	18
January	6	18
February	7	17
March	8	16
April	9	15
May	11	13

It was assumed that work done on the air during its passage through the fan ventilation system would raise its temperature by 2 deg F (1 deg C) before it entered the onion bulk.

5. Ventilation restrictions

For this study, it was assumed that on falling outside air temperatures, a frost guard thermostat would cut off the ventilating fan and the air supply at $28^{\circ}F$ ($-2^{\circ}C$).

With rising outside air temperatures, the ventilating fan was assumed to cut in at $31^{\circ}F$ ($-0.5^{\circ}C$).

Further constraints were assumed imposed by a differential thermostat operating between the bulk and the outside air.

On falling outside air temperatures, the ventilating fan was assumed to cut in at a bulk to air temperature difference of 6 deg F (3 deg C).

On rising outside air temperatures, the ventilating fan was assumed to cut out at a bulk to air temperature difference of 4 deg F (2 deg C).

These restrictions are set out in the flow diagram of Figure 1, in which

T_b = onion bulk temperature

$T(t)$ = outside air temperature at time t hours from sunrise

$T(t-1)$ = outside air temperature at the hour preceding time (t)

6. Hourly temperature changes of the bulk under "Blow" and "No Blow" conditions

6.1. The "Blow" situation

The temperature changes that will occur in 1 hour are considered; the temperature of the ventilating air is assumed constant over any given hourly period.

We distinguish between

$T_{ib}{}^{\circ}C$ = initial temperature of the bulk

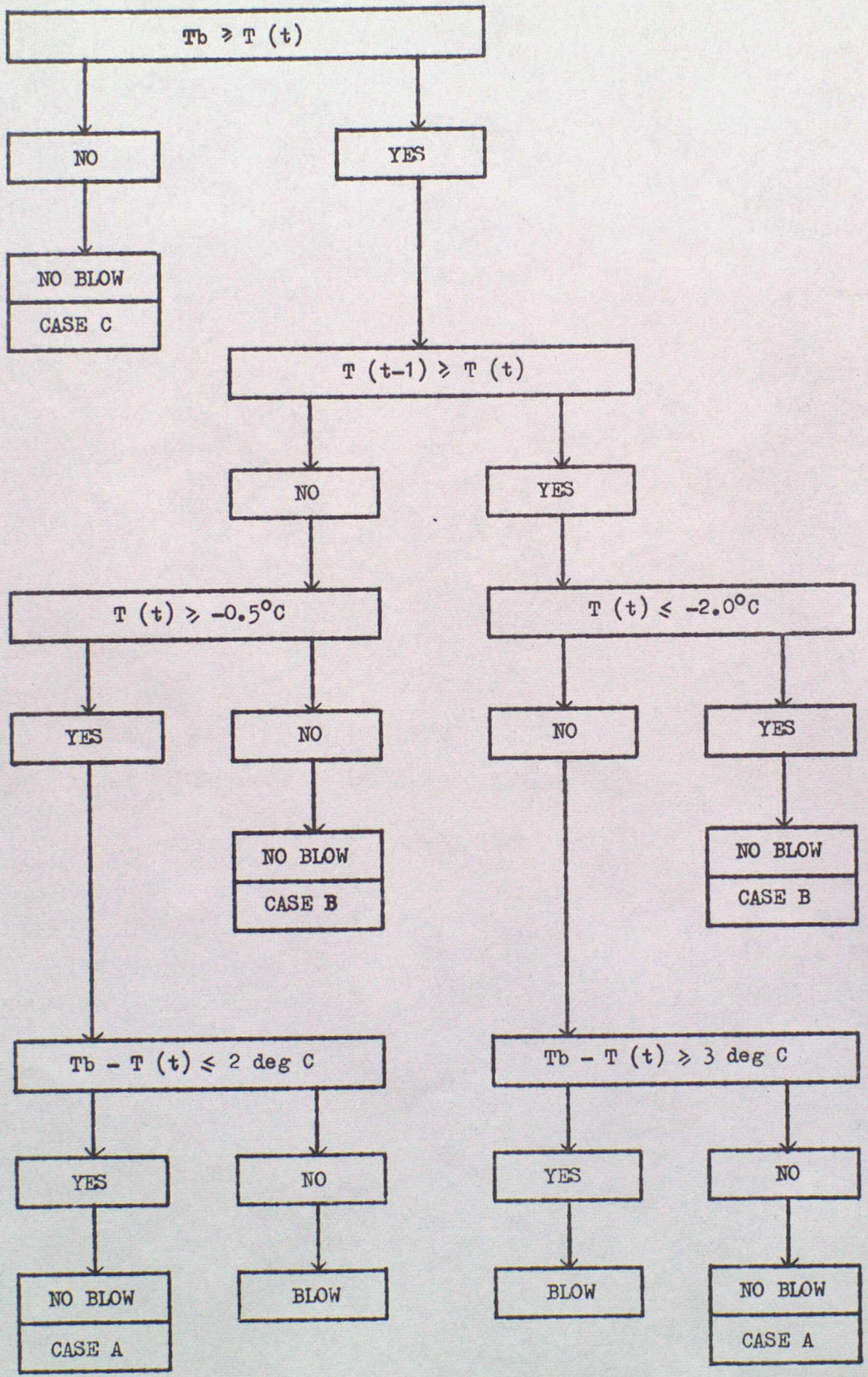
$T_{fb}{}^{\circ}C$ = final temperature of the bulk

$T^{\circ}C$ = outside air temperature

$(T+1)^{\circ}C$ = ventilating air temperature

With the bulk being ventilated, it was assumed that the consequences for the bulk of heat conduction through the fabric of the store might be ignored. In this situation, the building might reasonably be expected to be pressurised with any air infiltration from the inside to the outside. Any heat transfer through the fabric of the store, from the air inside to the air outside, should be in the same sense, and even if this were not so, air movement out of the bulk should minimise the heat transfer from the store structure to the surface of the bulk.

FIGURE 1


Tb ≥ T (t)
NO
YES
NO BLOW
CASE C
T (t-1) ≥ T (t)
NO
YES
T (t) ≥ -0.5°C
T (t) ≤ -2.0°C
YES
NO
NO
YES
NO BLOW
CASE B
NO BLOW
CASE B
Tb - T (t) ≤ 2 deg C
Tb - T (t) ≥ 3 deg C
YES
NO
YES
NO
NO BLOW
CASE A
BLOW
BLOW
NO BLOW
CASE A

In arriving at the temperature change of the onion bulk in this situation, only 2 factors were considered, the metabolic heat production of the onions and their heat loss by ventilation.

With T_{ib} in the range 0–10°C, the metabolic heat generated was assumed to be given by the expression

$$30 + \frac{70 - 30}{10}\left(\frac{T_{ib} + T_{fb}}{2}\right) \text{ Btu/ton/hour}$$

With T_{ib} in excess of 10 C, the metabolic heat generated was assumed to be 70 Btu/ton/hour.

The general expression,

Heat loss of bulk = Heat loss by ventilation – Metabolic heat production,

enables relation between T_{ib} and T_{fb} to be established. We consider the temperature change of 1 tonne of onions ventilated for 1 hour at 100 cfm.

Heat loss of bulk = Mass x specific heat x temperature change
$= 10^6 \times 0.83 \times (T_{ib} - T_{fb})$ cal.

Heat loss by ventilation = Heat uptake of air
= Mass x specific heat x temperature change
$= \left(\frac{100 \times 60}{12.75}\right) 454 \times 0.24 \times \left[\frac{T_{ib} + T_{fb}}{2} - (T+1)\right]$ cal.

Metabolic heat output (generally) $= \left[30 + 2\,(T_{ib} + T_{fb})\right] 256$ cal.

with temperature measured in degree C
454 gramme = 1 lb
1 Btu/ton/hour = 256 cal./tonne/hour

Substitution of numerical values in the general expression and simplifying leads to the relationship.

$$\boxed{T_{fb} = 0.941\ T_{ib} + 0.06\ T + 0.069} \quad \text{deg C}$$

With $T_{ib} > 10°C$

$$\boxed{T_{fb} = 0.941\ T_{ib} + 0.06\ T + 0.141} \quad \text{deg C}$$

6.2. "No Blow" situation – Case A

In this situation, the small temperature difference between the bulk and the ambient air (either within the store or outside), would make it reasonable to assume that the heat exchange of the bulk, by any process, would be slight.

With no heat exchange by through ventilation and/or stack effect, the whole of the metabolic heat was now regarded as being retained within the bulk,

The general expression

Heat gain of bulk = Metabolic heat output

enables relations between T_{ib} and T_{fb} to be established.

For 1 tonne of onions

Heat gain of bulk = Mass x specific heat x Temperature Change
$= 10^6 \times .83 \times (T_{fb} - T_{ib})$ cal.

Metabolic heat output (generally) $= \left[30 + 2\,(T_{ib} + T_{fb})\right] \times 256$ cal.

Substitution in the above general expression, and simplyfying, leads to the relationship.

$$T_{fb} = 1.0012\, T_{ib} + .009 \quad \text{deg C}$$

With $T_{ib} > 10^{\circ}C$

$$T_{fb} = T_{ib} + .0216 \quad \text{deg C}$$

6.3. "No Blow" situation - Case B

In this situation, the bulk is not blown because the frost guard thermostat is called into operation.

The heat transfer coefficient reported in Section 2, and determined for forced (turbulent) convective air flow through the bulk, is equally applicable to volume flows induced by "stack effect", but not applicable to the heat exchanges that occur at the external surfaces of the bulk.

6.3.1. Volume flows due to stack effect

The head P due to stack pressure can be written as

$$P = gH\,(\rho_T - \rho_{Ti})$$

where g = acceleration due to gravity
H = height of stack
ρ_T = air density at outside air temperature, T
ρ_{Ti} = air density at initial bulk temperature, T_{ib}

With the introduction of the perfect gas equation, we may write

$$P = \frac{gH\,(T_{ib} - T)\,\rho_{Tib}}{T} \quad \text{cgs units}$$

If P is evaluated in inches (static water gauge) to enable ready comparison with the fan pressures (of the order 1.0 inches) known to be required to overcome the resistance to air flow through a bulk, we find for typical values

$$\text{e.g. } H = 300 \text{ cm (10 ft)}$$

$$T_{ib} - T = 10 \text{ deg C}$$

$$T = 273^{\circ}K$$

that on substitution of numerical values

$$\frac{g \times 300 \times 10 \times .00129}{273} = g\,h' \times 2.54$$

that $h' = .0056$ inches (s.w.g) = stack pressure.

The conclusion is that the volume flows and heat exchanges due to stack pressures can be ignored.

6.3.2. Heat exchanges at the external surface of the bulk

We consider a typical bulk of, say, 400 tons. The overall dimensions of such a bulk are likely to be some 100 x 30 x 10 ft and the external surface area exposed to air movement (primarily the top surface) of the order 4000 ft^2. This is equivalent to 10 ft^2/ton of onions within the bulk.

Natural convective heat transfer at external surfaces

Adopting the ASHRAE expression appropriate to large horizontal plates (areas), the plate facing upward when heated, and in the turbulent flow range, as being the most appropriate to indicate orders of magnitude, we find h, the heat transfer coefficient given generally as

$$h = 0.19\,(T_b - T)^{\frac{1}{3}} \quad \text{Btu/hour/ft}^2\text{/deg F}$$

where T_b = bulk surface temperature

Making the usual assumption that the effective surface temperature for convective transfer is that of the surface film of air, and the further usual assumption that this temperature is a mean of the bulk and air temperatures, we may write

$$h = 0.19\left(\frac{T_{ib} - T}{2}\right)^{\frac{1}{3}}$$

The following numerical relationships result

$(T_{ib} - T)$	h (Btu/hour/ft^2/deg F)	heat loss (Btu/ton/hour)
1.8 deg F (1 deg C)	.18	1.6
9 deg F (5 deg C)	.31	13
18 deg F (10 deg C)	.40	36

Radiative transfer at external surfaces

Assuming that the surfaces to which the bulk radiates are close to the external air temperature and that we can reasonably adopt an Angle Factor of unity, a general expression for the radiative transfer of heat from the bulk is given by

$$\text{Radiative Loss} = E\,\sigma\,(T_{ib}^4 - T^4)$$

where E = surface transmission coefficient
= .95 (say)

σ = Stefans constant = 5.7×10^{-5} erg/cm^2/sec/deg^4

and temperatures are measured in degrees absolute. In numerical terms, on conversion to British units we have

$$\text{Radiative Loss} = E\,\sigma\,(T_{ib}^4 - T^4) \times 10^{-7} \text{ watt/cm}^2$$
$$= E\,\sigma\,(T_{ib}^4 - T^4) \times 10^{-10} \text{ k watt/cm}^2$$
$$= E\,\sigma\,(T_{ib}^4 - T^4) \times 929 \times 10^{-10} \text{ k watt/ft}^2$$
$$= E\,\sigma\,(T_{ib}^4 - T^4) \times 929 \times 3412 \times 10^{-10} \text{ Btu/hour/ft}^2$$
$$= E\,\sigma\,(T_{ib}^4 - T^4) \times 929 \times 3412 \times 10^{-9} \text{ Btu/ton/hour}$$

and the following numerical relationships result:

T_{ib}	T	$(T_{ib} - T)$	heat loss (Btu/ton/hour)
273	272	1 deg C	13.9
273	268	5 deg C	68.0
273	263	10 deg C	132.2

The conclusion is that both convective and radiative transfers and likely to be significant when compared with the metabolic heat output (of the order 30 Btu/ton/hour) and that in examining the heat balance and temperature change of the bulk, the following general expression should be considered to establish relations between T_{ib} and T_{fb}.

The general expression for this situation is

Heat loss of bulk = Convective heat loss + Radiative heat loss
- Metabolic heat output.

If heat exchanges at the surface are distributed through the bulk, then the temperature change of 1 tonne of onions, in 1 hour follows from:

Heat loss of bulk = Mass x specific heat x temperature change
= $10^6 \times .83 \times (T_{ib} - T_{fb})$ cal.

Convective heat loss = Transfer coefficient x area x temperature difference

$$= 0.19 \left(\frac{T_{ib} + T_{fb} - 2T}{4}\right)^{\frac{1}{3}} \left(\frac{9}{5}\right)^{\frac{1}{3}} \times 10 \times \left(\frac{T_{ib} + T_{fb} - 2T}{4}\right) \left\{\frac{9}{5}\right\} \times 256 \text{ cal.}$$

$$= 167.73 \, (T_{ib} + T_{fb} - 2T)^{4/3} \text{ cal.}$$

where temperatures are measured in deg C and 1 Btu/ton = 256 cal/tonne.

Radiative heat loss $= E \sigma \left[\left(\frac{T_{ib} + T_{fb}}{2}\right)^4 - T^4\right] \times 929 \times 3412 \times 256 \times 10^{-9}$ cal.

and when temperatures are measured in deg C

$$= 4.39 \times 10^{-5} \left[\left\{\frac{T_{ib} + T_{fb}}{2} + 273\right\}^4 - \{T + 273\}^4\right] \text{ cal.}$$

Metabolic heat output $= [30 + 2 \, (T_{ib} - T_{fb})] \times 256$ cal.

The above expressions assume a mean surface temperature for the bulk during the hour of $\frac{T_{ib} + T_{fb}}{2}$

Simplifying this expression leads to

$$T_{fb} = T_{ib} + .00925 - 2.02 \times 10^{-4} [T_{ib} + T_{fb} - 2T]^{4/3}$$
$$+ 52.86 \times 10^{-12} [T + 273]^4$$
$$- 3.303 \times 10^{-12} [T_{ib} + T_{fb} + 546]^4$$

A sensitivity analysis suggests that on the RHS of this expression, for the components involving powers of temperature (other than unity) there is very little error involved in assuming $T_{fb} = T_{ib}$.

A final expression is given by

$$T_{fb} = T_{ib} + .00925 - 5.09 \times 10^{-4} (T_{ib} - T)^{4/3}$$
$$+ 52.86 \times 10^{-12} (T + 273)^4$$
$$- 52.86 \times 10^{-12} (T_{ib} + 273)^4 \quad \text{deg C}$$

With $T_{ib} > 10^{\circ}C$

$$T_{fb} = T_{ib} + .0216 - 5.09 \times 10^{-4} (T_{ib} - T)^{4/3}$$
$$+ 52.86 \times 10^{-12} (T + 273)^4$$
$$- 52.86 \times 10^{-12} (T_{ib} + 273)^4 \quad \text{deg C}$$

6.4. "No Blow" situation - Case C

In this situation, the bulk is not blown since the ambient air is warmer than the bulk.

As in Case B, we may ignore the through ventilation flows due to stack pressure.

As in Case B, the radiative exchanges are important and are calculated in the same way; the sense of the net radiative exchanges is now from the surroundings to the bulk surfaces.

The prime difference from Case B in the value assigned to the natural convective heat transfer coefficient.

With surrounding air warmer than the bulk surface, heat transfer to the bulk by natural convection is inhibited. Nevertheless, because of infiltration flows over the rough surface of the bulk, some exchange will take place.

The ASHRAE recommendation appropriate to large horizontal plates (areas) in the turbulent flow range, for cool plates facing upwards, is that a coefficient somewhat less than half of that appropriate to warm plates facing upwards should be adopted.

We assume orders of magnitude will be correctly indicated if, in this situation

$$h = 0.09\ (T - T_b)^{\frac{1}{3}} \quad \text{Btu/hour/ft}^2\text{/deg F.}$$

Introducing a correction for film temperature, we have

$$h = 0.09\ \left(\frac{T - T_{ib}}{2}\right)^{\frac{1}{3}}$$

To establish relations between T_{fb} and T_{ib} we use the general expression

Heat gain of bulk = Metabolic heat + Convective heat gain + Radiative heat gain

If heat exchanges at the surface are distributed through the bulk, then the temperature change of 1 tonne of onions, in 1 hour follows from

Heat gain of bulk = Mass x specific heat x temperature change

$= 10^6 \times .83 \times (T_{fb} - T_{ib})$ cal.

Convective heat gain = Transfer coefficient x area x temperature difference

$$= 0.09 \left(\frac{2T - T_{ib} - T_{fb}}{4}\right)^{\frac{1}{3}} \left(\frac{9}{5}\right)^{\frac{1}{3}} \times 10 \times \left(\frac{2T - T_{ib} - T_{fb}}{4}\right) \left(\frac{9}{5}\right) \times 256 \text{ cal.}$$

$$= 79.45\ (2T - T_{ib} - T_{fb})^{4/3} \text{ cal.}$$

$$\text{Radiative heat gain} = 4.39 \times 10^{-5} \left[\left(T + 273\right) - \left(\frac{T_{ib} + T_{fb}}{2} + 273\right)^4\right] \text{ cal.}$$

$$\text{Metabolic heat gain} = \left[30 + 2\ (T_{fb} - T_{ib})\right] \times 256 \text{ cal.}$$

The above expressions assume a mean surface temperature for the bulk during the hour of $\frac{T_{ib} + T_{fb}}{2}$

Simplifying this expression leads to

$$T_{fb} = T_{ib} + .00925 + 2.41 \times 10^{-4} (T - T_{ib})^{4/3} + 52.94 \times 10^{-12} (T + 273)^4 - 52.94 \times 10^{-12} (T_{ib} + 273)^4 \quad \text{deg C}$$

With $T_{ib} > 10^{o}C$

$$T_{fb} = T_{ib} + .0216 + 2.41 \times 10^{-4} (T - T_{ib})^{4/3} + 52.94 \times 10^{-12} (T + 273)^4 - 52.94 \times 10^{-12} (T_{ib} + 273)^4 \quad \text{deg C}$$

7. Results

7.1 The estimated onion bulk temperatures at the end of each day (24 hourly temperature changes) are shown in Figures 2 to 5, for the past 7 seasons. An initial bulk temperature of 10°C was taken in every case. The implications of an initial bulk temperature of 20°C are also shown in one or two seasons. The outside air temperatures used in the calculations were those observed at the Arthur Rickwood Experimental Husbandry Farm, Mepal, Cambridge. The table below shows the departure from the long period average of the monthly mean temperatures recorded in the Region over the seasons studied.

Table Departure from average of Monthly mean temperature (at Cambridge) (deg C)

Year	67	68	69	70	71	72	73
October	+0.8	+2.5	+3.2	+1.1	+0.7	+0.5	-1.1
November	-1.7	-0.5	-0.3	0	-1.1	-0.4	-1.1
December	-1.2	-2.0	-1.6	-0.5	+1.6	+1.0	+0.3
Year	68	69	70	71	72	73	74
January	+0.3	+2.3	+0.4	+1.0	+0.3	+0.8	+2.4
February	-1.6	-1.6	-0.6	+0.9	+0.7	+0.5	+1.9
March	+0.9	-2.4	-2.8	-1.1	+0.8	+0.4	0
April	0	-1.2	-1.8	-1.0	-0.1	-1.1	-0.6
May	-1.2	+0.4	+1.8	0	-0.5	+0.2	-0.6

From such data we may assess whether a given month was noticeably mild or otherwise. The standard deviation of monthly mean temperature at Cambridge is around 2 deg C in January and February and 1 to 1.5 deg C in the remaining months shown. The only month that might be considered extreme in the sample examined was October 1969 (departure from average > 2 standard deviations).

7.2 There are at present almost no commercial onion stores fitted out and operated in the manner envisaged in this note. The one or two where procedures approximate to those outlined enable some rough check to be made on the calculations.

Information is available from 2 separate stores in the Region, whose managers have been good enough to make temperature observations at intervals of a few days available to us.

A comparison of the range of observed and calculated onion bulk temperatures is as follows:

	Store 1	Store 2	Calculated
December 1973	37°-45°F (3°-7°C)	33°-46°F (1°-8°C)	1°-4°C
January 1974	42°-46°F (6°-8°C)	37°-48°F (3°-9°C)	1°-6°C
February 1974	37°-45°F (3°-7°C)	38°-46°F (3°-8°C)	3°-6°C
March 1974	38°-46°F (3°-8°C)	-	3°-8°C

A comparison of spot values of temperature, where the records from the 2 stores are broadly in phase, and in agreement on bulk temperatures leads to the following:

	Store temperatures	Calculated
18-19 December 1973	37°F (3°C)	3°C
10-11 February 1974	38°-39°F (4°C)	4°C
24 January 1974	46°-48°F (8°-9°C)	6°C

An observed temperature in store of 50°F (10°C) after the winter of 1973-1974 was first reached in mid-May, i.e. at much the same time as that indicated by the calculations.

8. Conclusions

(i) The calculations employed to estimate onion bulk temperature provide a reasonable approximation to those likely to be experienced in practice.

(ii) It would appear that an automatic ventilation system (which blows the onions on every occasion on which there is a sensible temperature difference between the bulk temperature and the cambient, outside air) should be capable of keeping the bulk cool, without refrigeration, for substantial periods.

Over the critical period from mid-November onwards, a bulk temperature of 5°C (41°F) or less should be maintained at least until the end of March.

Bulk temperatures of between 5°C and 10°C (41°F to 50°F) should be held during April.

Bulk temperatures in excess of 10°C for any length of time should not generally be expected until well into May.

(iii) The effects of high initial bulk temperatures would seem to be lost within about 2 weeks of the beginning of blowing for long term storage.

(iv) Fans might be called into operation for total of 750–800 hours during a storage season which extends from October through to May.

9. Further Work

The implications of these storage temperatures for keeping quality are to be discussed in a later memorandum.

Acknowledgements

I should like to thank Mr P Richard, ADAS Eastern Region for the collaboration he has given.

The data provided by commercial growers has been an invaluable check on the calculations. Without their help and experience one might have been reluctant to undertake the study.

Meteorological Office
CAMBRIDGE

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FIGURE 2

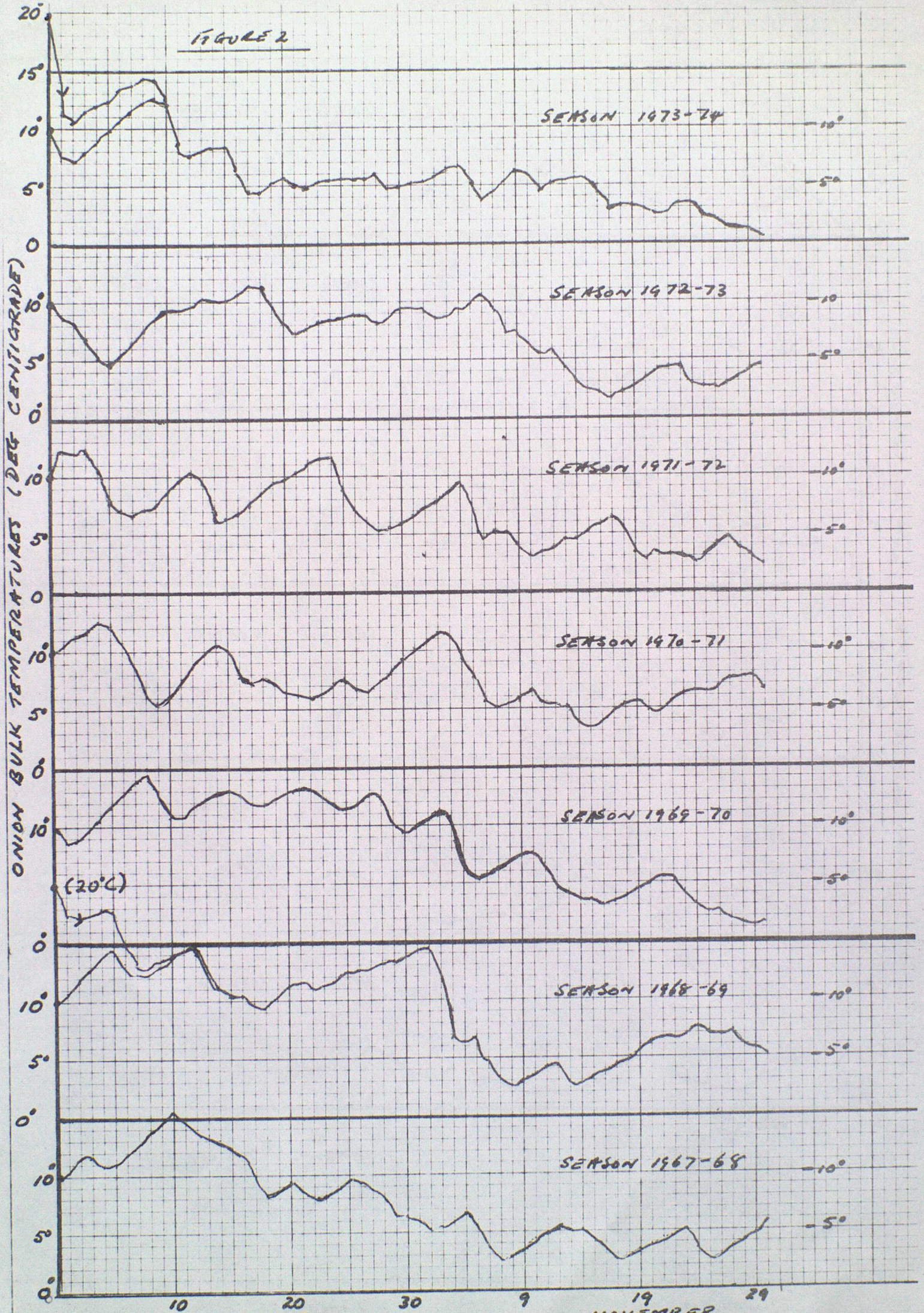

ONION BULK TEMPERATURES (DEG CENTIGRADE)
SEASON 1973-74
SEASON 1972-73
SEASON 1971-72
SEASON 1970-71
SEASON 1969-70
(20°C)
SEASON 1968-69
SEASON 1967-68
20°
15°
10°
5°
0°
-10°
-5°
10
20
30
9
19
29
OCTOBER
NOVEMBER

FIGURE 3

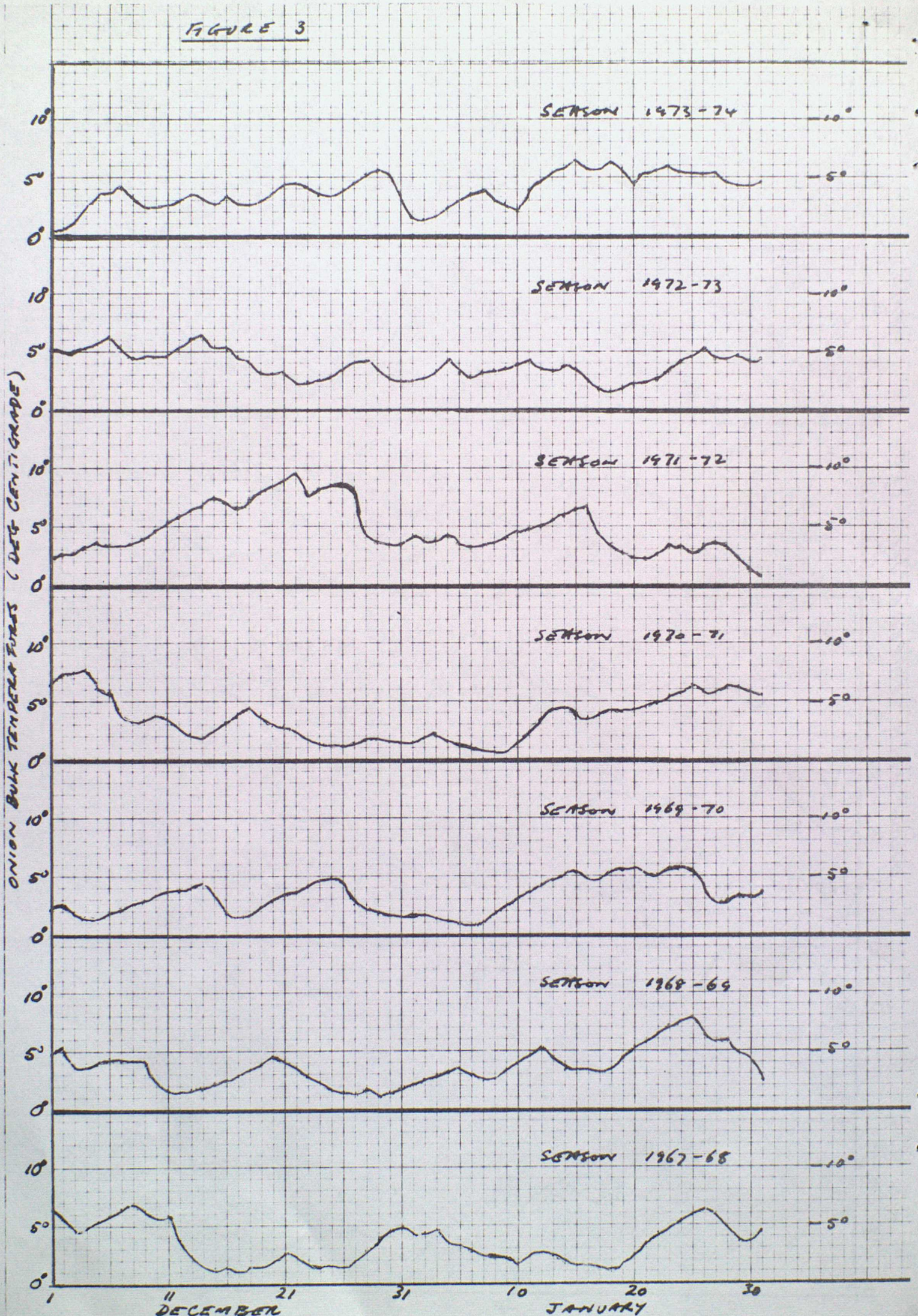
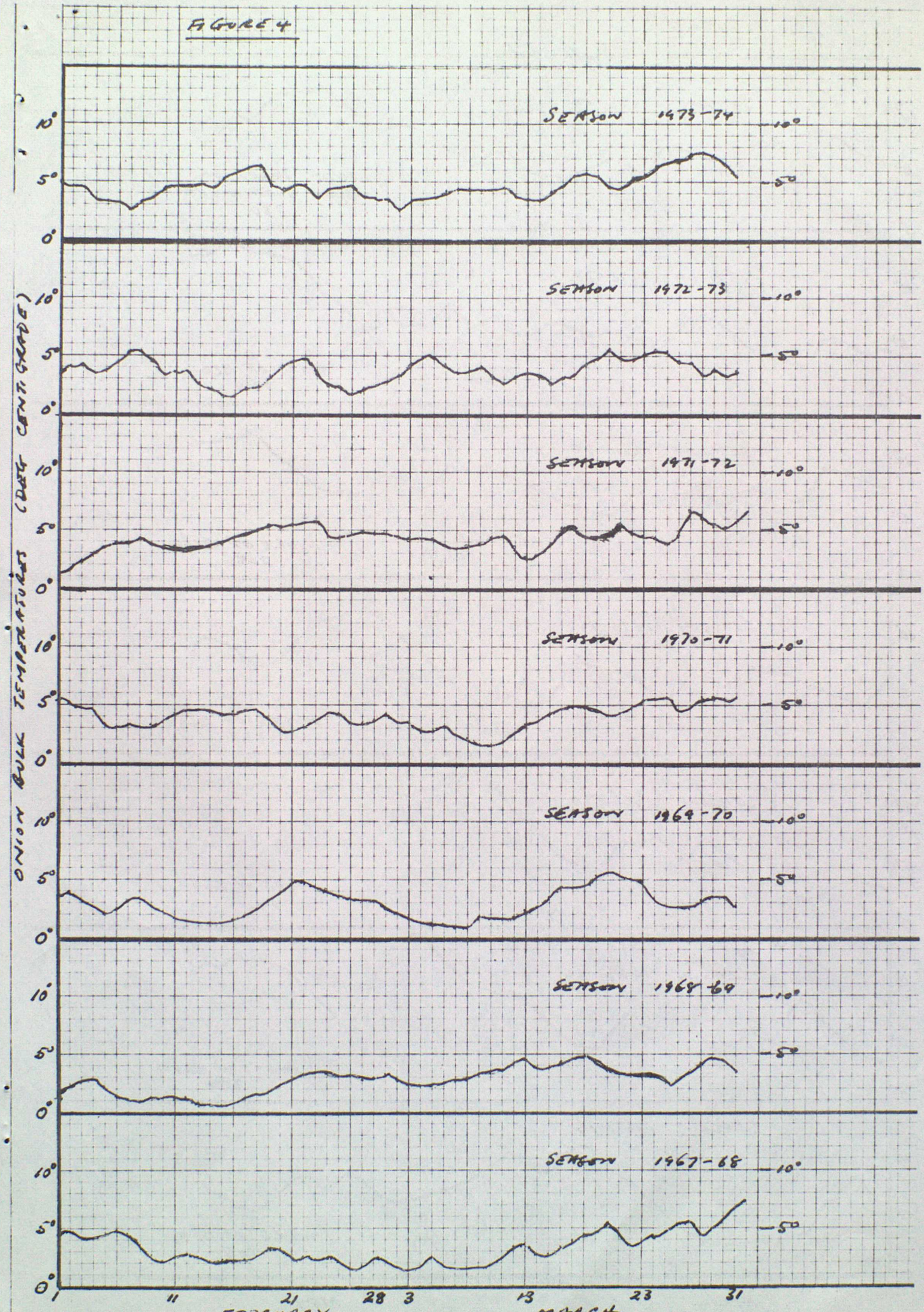
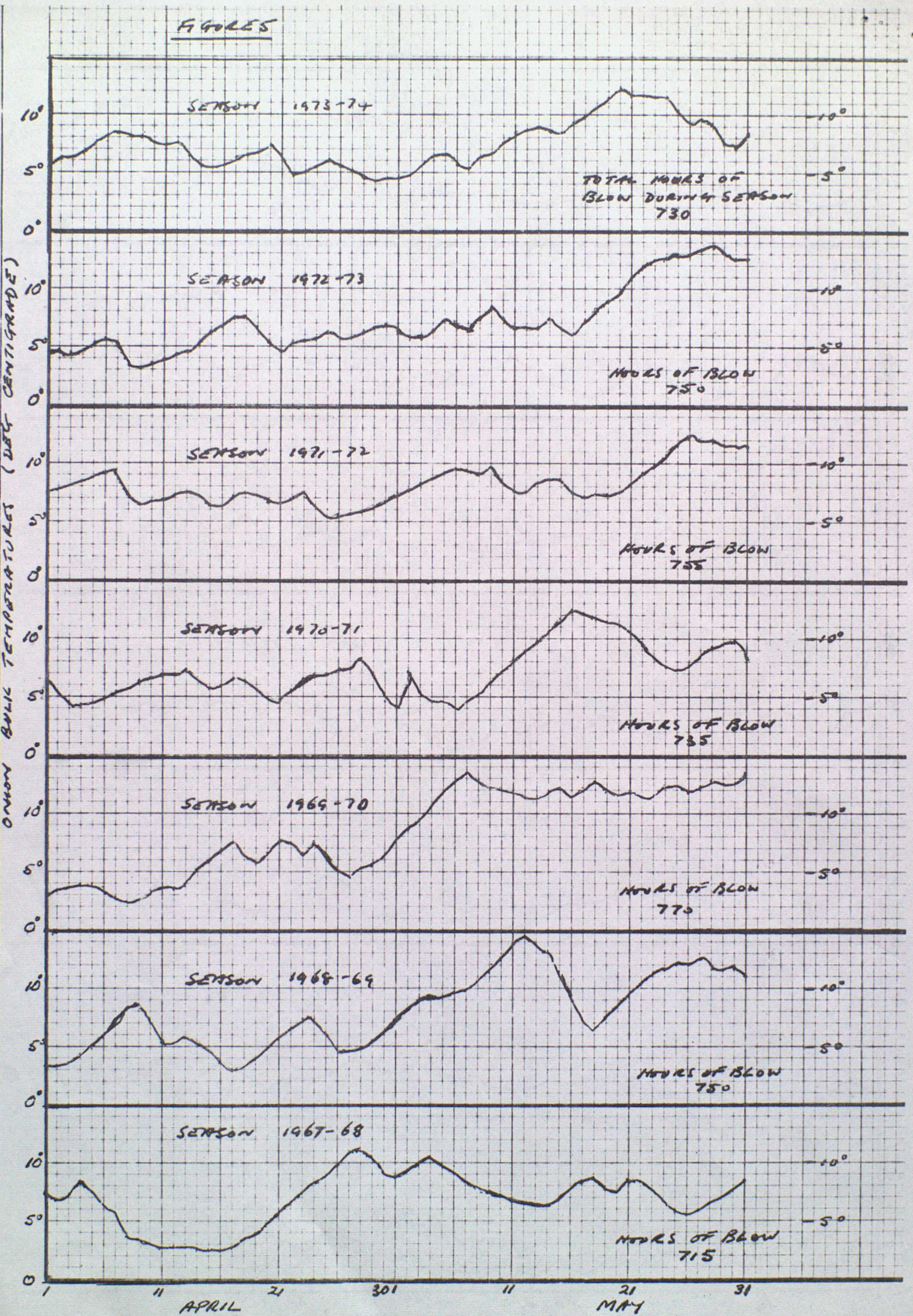

SEASON 1973-74
SEASON 1972-73
SEASON 1971-72
SEASON 1970-71
SEASON 1969-70
SEASON 1968-69
SEASON 1967-68
10°
5°
0°
-10°
-5°
ONION BULK TEMPERATURES (DEG. CENTIGRADE)
1
11
21
31
10
20
30
DECEMBER
JANUARY

FIGURE 4


SEASON 1973-74
SEASON 1972-73
SEASON 1971-72
SEASON 1970-71
SEASON 1969-70
SEASON 1968-69
SEASON 1967-68
10°
5°
0°
ONION BULB TEMPERATURES (DEGR. CENTI. GRADE)
1
11
21
28
3
13
23
31
FEBRUARY
MARCH.

FIGURES


SEASON 1973-74
TOTAL HOURS OF BLOW DURING SEASON 730
SEASON 1972-73
HOURS OF BLOW 750
SEASON 1971-72
HOURS OF BLOW 755
SEASON 1970-71
HOURS OF BLOW 735
SEASON 1969-70
HOURS OF BLOW 770
SEASON 1968-69
HOURS OF BLOW 750
SEASON 1967-68
HOURS OF BLOW 715
ONMON AVG TEMPERATURES (DEG CENTIGRADE)
10°
5°
0°
-10°
-5°
1
11
21
30
11
21
31
APRIL
MAY